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CLINICAL COMMENTARY

REHABILITATION FOLLOWING MEDIAL PATELLOFEMORAL LIGAMENT RECONSTRUCTION FOR PATELLAR INSTABILITY

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ABSTRACT

Patellar instability is a common problem seen by physical therapists, athletic trainers and orthopedic surgeons. Although following an acute dislocation, conservative rehabilitation is usually the first line of defense; refractory cases exist that may require surgical intervention. Substantial progress has been made in the understanding of the medial patellofemoral ligament (MPFL) and its role as the primary stabilizer to lateral patellar displacement. Medial patellofemoral ligament disruption is now considered to be the essential lesion following acute patellar dislocation due to significantly high numbers of ruptures following this injury. Evidence is now mounting that demonstrates the benefits of early reconstruction with a variety of techniques. Recently rehabilitation has become more robust and progressive due to our better understanding of soft tissue reconstruction and repair techniques. The purpose of this manuscript is to describe the etiology of patellar instability, the anatomy and biomechanics and examination of patellofemoral instability, and to describe surgical intervention and rehabilitation following MPFL rupture.

Key words: Knee, patellar instability, rehabilitation, surgery

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BACKGROUND AND PURPOSE

Patellar instability is a common complaint seen by physical therapists, athletic trainers and surgeons. Patellar instability in athletes is a general umbrella term used for either patellar subluxation or dislocation.[1] Dislocation and subluxations can occur due to repetitive micro trauma over time creating a gradual progression of instability of a chronic nature. However, instability can also occur due to an acute event such as a patellar dislocation in which localized trauma has forced the patella laterally out of the safe confines of the patellar trochlea of the distal femur. Lateral patellar dislocations are the most common knee dislocation injury among young adults.[2] One structure that helps maintain patellar stability is the medial patellofemoral ligament (MPFL). Substantial progress has been made in the understanding of the MPFL and its role as the primary stabilizer to lateral patellar displacement. MPFL disruption is now considered to be the essential lesion following acute patellar dislocation due to significantly high numbers of ruptures following this injury. Evidence is now mounting that demonstrates the benefits of early reconstruction with a variety of techniques.

Actual dislocations of the patella represent a sparse 2%-3% of all knee injuries.[3] Historically these injuries have occurred more commonly in females than in males.[4] Nonoperative treatment has been recommended for this injury,[5,6] however, conservative treatment of this condition is often of little value as recurrent dislocation occurs in up to 15% to 44% of patients who have sustained a traumatic patellar dislocation.[7-11] In persons who have had two prior episodes of dislocations the recurrence rate jumps to 49%.[8] Maenpaa and Lehto report that in more than half of the patients, a first time patellar dislocation left untreated or treated nonoperatively will lead to instability and recurrent dislocations.[12] These findings are similar to those of McManus et al who report that the natural history of a nonoperatively treated patellar dislocation involves re-dislocation in one of six cases; other residual symptoms in two of six, and three of six cases will be asymptomatic.[13] Collectively these studies indicate that conservative treatment with a period of immobilization followed by physical therapy is associated with re-dislocation rates of upwards of 63%. Those who do not re-dislocate may continue to have persistent patellofemoral problems and disability and even femorapatellar osteoarthrosis.[14] Risk factors for recurrent instability include young age, immature physes, sports-related injuries, patella alta and trochlear dysplasia.[9] Other predisposing factors that can contribute to chronic patellar instability include: femoral anteversion, external tibial torsion, genu valgum, patellar dysplasia, vastus medialis obliquus atrophy, pes plannus, and generalized ligamentous laxity.[15]

Patellar instability can be the result of multiple problems including structural anatomical abnormalities, or insufficient soft tissue restraints.[16] Examples of structural abnormalities and insufficient soft tissue restraints include vastus medialis weakness, tight lateral structures such as the tensor fascia lata/iliotibial band, and lateral retinaculum. Other anatomical variations that can create this multifactorial problem include patella alta, increased quadriceps angle, excessive tibial tubercle-trochlear groove distance, trochlear dysplasia and ligament hyperlaxity.[6,17-19] The purpose of this manuscript is to describe the etiology of patellar instability, the anatomy and biomechanics and examination of patellofemoral instability, and to describe surgical intervention and rehabilitation following MPFL rupture.

ANATOMY

Patellar stability is afforded by both active and passive restraints. Active restraints to the anterior knee are the quadriceps muscle group. Both the rectus femoris and the vastus intermedius have a direct line of pull along the long axis of the femur. The vastus lateralis and the vastus medialis both have, although at slightly different angles, an oblique insertion onto the patella which allows for medial and lateral patellar stabilization. Collectively these muscles provide dynamic patellofemoral stability. Passive patellar stability is provided by several soft tissue structures including the patellar tendon and the patellar retinaculum. The patellar tendon is the distal component of the quadriceps tendon. The patellar retinaculum is different on the lateral and medial sides. The lateral complex is more intricate and includes two different structures: the superficial oblique retinaculum and the deep transverse retinaculum.[20] The medial side of the retinacular structures are quite different and include the medial meniscopatellar ligament and the MPFL. In the three-layer description of the medial side of the knee, the MPFL lies in the second layer.[21] The MPFL was originally thought to be present in only 29%-89% of knees.[22,23] It is now commonly accepted that this structure is present in all knees and that it is the major medial static stabilizer of the patellofemoral joint.[24-27]

The MPFL is unique in that the anterior portion interdigitates with the deep fibers of the vastus medialis obliquus (VMO) (Figure 1), suggesting that it might work together with the VMO supplying medial stabilization. The VMO is the oblique, medial portion of the quadriceps that is thought to provide dynamic medial patellofemoral restraint. In concert these two structures appear to draw the patella from its slightly lateralized position in full extension, moving the patella medially toward the trochlea such that the patella enters the trochlea during early knee flexion movements.[28]

The anatomical origin of the MPFL has been described in multiple locations. Warren and Marshall report that the MPFL is located at the region of the superficial medial collateral ligament.[21] Feller and colleagues report it to be anterior to the medial epicondyle.[29] Steensen describes the origin as the actual anterior medial epicondyle,[30] while multiple authors report that its origin is simply at the medial epicondyle.[27,31-34]

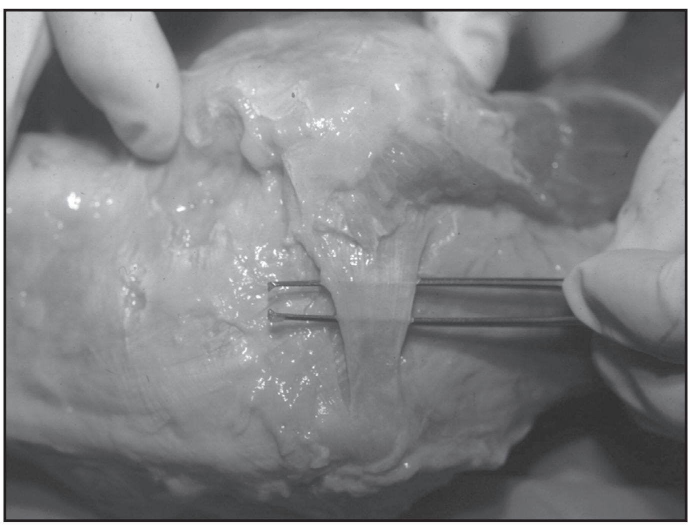

Figure 1. *A image of the medial aspect of the right knee with the patella at the top. The MPFL, passing over the forceps, links the proximal half of the medial border of the patella to the medial femoral condyle. The superficial fascia and distal part of the vastus medialis obliquus have been removed. Permission granted by Mountney J, Senavongse W, Amis AA, Thomas NP.Tensile strength of the medial patellofemoral ligament before and after repair or reconstuction. J Bone Joint Surg. 2005;87B(1):36-40.*

BIOMECHANICS

Numerous studies have examined the biomechanical contributions and restraint provided by the MPFL. Amis has shown that the native MPFL is not a very robust ligament; when compared to others in the knee it only withstands loads of about 208N when tested to failure at 25 mm of displacement.[31] The MPFL provides from 50-60% of the restraint to lateral patellar translation during the ranges of 0-30 degrees of knee flexion.[22,24,25] If the MPFL is sectioned, the patella displaces laterally, even with the other medial stabilizers intact.[25,26] Amis and colleagues suggest that this ligament is tightest near full extension and loses tension as the knee is flexed.[31] However, McCulloch et al report that the actual highest increase in strain occurred between 25-30 degrees of knee flexion.[35] This may be biomechanically appropriate as the patella generally enters the trochlea near 15-20 degree of knee flexion and thus has improved bony support and congruence in that range and further into flexion.

The MPFL rupture at a mean elongation of 26 +/-7 mm in cadaveric specimens.[36] Because the mean length of the MPFL is 53 mm, ruptures occur at approximately 49% strain.[37] The average width of the MPFL is 1.9 cm.[37]

TEAR CLASSIFICATION

Nomura described a classification for tears based on surgical findings from 67 knees following acute or recurrent patellar dislocation.[38] Focal injury was seen in 17/18 knees with acute patellar dislocation. These injuries were categorized into Type I and Type II injuries. Type I are avulsion type or detachments of the ligament from its femoral attachment. Type II injuries are intra-substance tears of the ligament. The location of these intra-substance tears was usually near the normal femoral attachment of the ligament. In all knees with recurrent patellar dislocation the MPFL was abnormal. Abnormality was described as three different types: Type I included no MPFL injury that was seen by gross inspection, but ligament was loose at its femoral attachment; Type II consisted of scar tissue either in the body of the MPFL or between the ligament and its femoral attachment (but both are loose); Type III was termed "absent" type, in which the ligament consisted of a remnant that lacked continuity or could not be identified.

HISTORY

As with most knee conditions, obtaining a subjective medical history is critical to the success of any evaluation of musculoskeletal injuries and is never more important than in the knee.[39] The medical history should be performed in a consistent and orderly fashion with every patient in order to obtain crucial information without missing important findings.[40] Most patients will tell you their problems if you listen closely and ask the appropriate questions. Acute traumatic patellar dislocation can occur due to a single inciting incident; however subluxation of the patella may occur as recurrent patellar instability due to repetitive minor trauma. In some instances there may not be a blow to the knee during the injury mechanism. In general, patellar dislocations or subluxations occur in the lateral direction however, although rare, medial displacement can also occur. In most cases these injuries are the result of a noncontact, quick turning incident, in a single direction with the femur and tibia moving in opposite directions. This can occur during a plant and cut maneuver or trying to fake someone out quickly, in which the femur internally rotates while the tibia remains relatively externally rotated. Regardless of the mechanism, the athlete almost always feels a vivid sensation of bony subluxation. The patient may describe the patella's position grossly laterally or just a medial prominence. Do not be fooled, as the medial prominence may actually be the uncovered medial femoral condyle that can clearly be seen due the laterally displaced patella. The laterally displaced patella will stay displaced as long as the knee remains flexed. With the help of a sports physician, athletic trainer or therapist movement of the knee into extension will usually cause an abrupt relocation, with which a "clunk" or shifting sensation is felt, providing significant pain relief. Historically a first time acute patellar dislocation results in significant effusion in the knee. In the athlete with a chronic recurrent dislocation the swelling and effusion may be much more subtle.

EXAMINATION

General Examination

Any evaluation of a knee disorder should be performed with the patient dressed in shorts with the knees clearly exposed. Physical examination of patellar instability can be done in the face of an acute dislocation, which will be done completely different than that of the athlete with a more chronic condition. Pending the time frame between dislocation and examination the patella may still be dislocated and displaced laterally. Just because the patella presents in its correct position it cannot be assumed that it was not dislocated previously. Within several hours of an acute dislocation, a significant effusion will be present. This may limit the ability to perform a thorough examination due to limited knee mobility due to swelling. There will likely be tenderness along the medial retinaculum, the MPFL and the adductor tubercle. With these described symptoms it is best to assume that the patella has been dislocated until proven otherwise. Swelling, range of knee motion, palpation, and the amount of passive patellar mobility should always be compared to the uninvolved side. A more complete physical examination can be performed on the suspected recurrent patellar dislocation patient as they will not be as irritable as the patient with an acutely dislocated patella.

STANDING EXAMINATION

In the standing position the patient should be assessed for multiple things. Equality of weight bearing can be easily viewed in this position, as can varus and valgus alignment. An athlete with miserable malalignment syndrome (MMS) can be predisposed to patellar instability.[40] MMS is a constellation of several functional deformities which include internal rotation of the femur, with accompanied bayonet deformity of the tibia, external tibial torsion, and pronated feet. Due to significant swelling, and because maximal capsular volume of the knee is in 25-30 degrees of knee flexion, the patient may stand or walk with the knee in a flexed position.

SEATED EXAMINATION

The seated examination allows the clinician to view the knee in resting position from anterior, medial and lateral aspect. Where is the patella sitting passively in a relaxed seated position? In a patient with a large degree of patella alta the patella will be resting high and laterally in what is called “grasshopper eyes” position. Patella alta can be determined by an Insall-Savalti measurement of greater than 1:1 ratio of patellar tendon length to patellar height. If the length of the patellar tendon is greater than the height of the patella a patella alta exists. This may predispose the athlete to recurrent patellar subluxations or dislocations due to excessive patellar tendon length.

The tibial tubercle sulcus angle can be measured with the athlete sitting over the edge of the treatment table with the knee flexed 90 degrees. The clinician observes the position of the tibial tubercle relative to the patellar center. The first line, a vertical line drawn from the center of the patella while the second is drawn from the center of the patella to the tibial tubercle. The tibial tubercle should be within the femoral trochlea when the knee is flexed 90 degrees. Controversy exists on what a normal angle shoulder be, as ranges from 0 degrees to 10 degrees have been reported.[41,42]

Passive and active patellar tracking can also be assessed in the seated position. The tripod position, (leaning backwards slightly supported by both hands with a slight posterior pelvic tilt) is assumed to decrease hamstring tightness during testing. The clinician passively extends the relaxed patients knee from flexion to full extension. During this movement the patella translates from a slightly lateral position in flexion to a medial position as the knee extends, and eventually back laterally again near full extension. Slight variations sometime exist between individuals and even between right and left knees of the same individual, so small deviations should not be of great concern. As this is a passive test, it assesses osseous and non-contractive tissues. Excessive lateral gliding usually indicates tightness of the superficial retinacular fibers, whereas excessive tilting would indicate excessive deep retinacular restraint. Following performance of the passive portion of this test, the clinician should examine an active component by having the athlete actively extend their knee fully. A similar type of movement should be seen if passive patellar tracking is normal. The clinician should watch for an abrupt lateral displacement between the range of 20-30 degrees of flexion to full extension as the patella is deviated or subluxed laterally. This may be indicative of a dysfunctional vastus medialis obliquus muscle lacking dynamic medial stability.

Strength can be tested via manual muscle testing of the quadriceps and hamstring muscle groups while seated. Manual muscle testing of hip muscles can be done in supine, side lying and prone. Adequate strength of all hip muscles and musculature of the trunk/core is needed to ensure proper proximal control.

SUPINE EXAMINATION

Supine examination includes examination of passive patellar mobility, knee swelling and effusion and manual muscle testing of proximal hip musculature. Assessment of passive patellar mobility is done in slight (20-30 degrees) of knee flexion, to engage the trochlea. The patella is then passively translated in both the medial and lateral directions in the frontal plane (Figure 2). Patellar mobility is described in quadrants of movement. The width of the entire patella is four quadrants. Thus two quadrants of movement would indicate movement that is equal to half the patella’s width. Normal patellar mobility is from 1-3 quadrants of passive movement in either direction. Less than 1 quadrant of passive mobility demonstrates hypomobility while passive movement greater than 3 quadrants demonstrates hypermobility.[42] Following MPFL reconstruction passive mobility of 2 quadrants is desirable in the medial and lateral directions.

Swelling and joint effusion should be measured in all patients complaining of knee pain. Circumferential measurements can be taken at several different spots around the knee; In particular, measuring at the joint line is suggested for generalized joint effusion. An additional location in a patient with suspected patellar instability would be at an area approximately 10 cm proximal to the knee joint which is the area around the vastus medialis oblique which may be selectively atrophied due to pain and inhibition from knee pain.

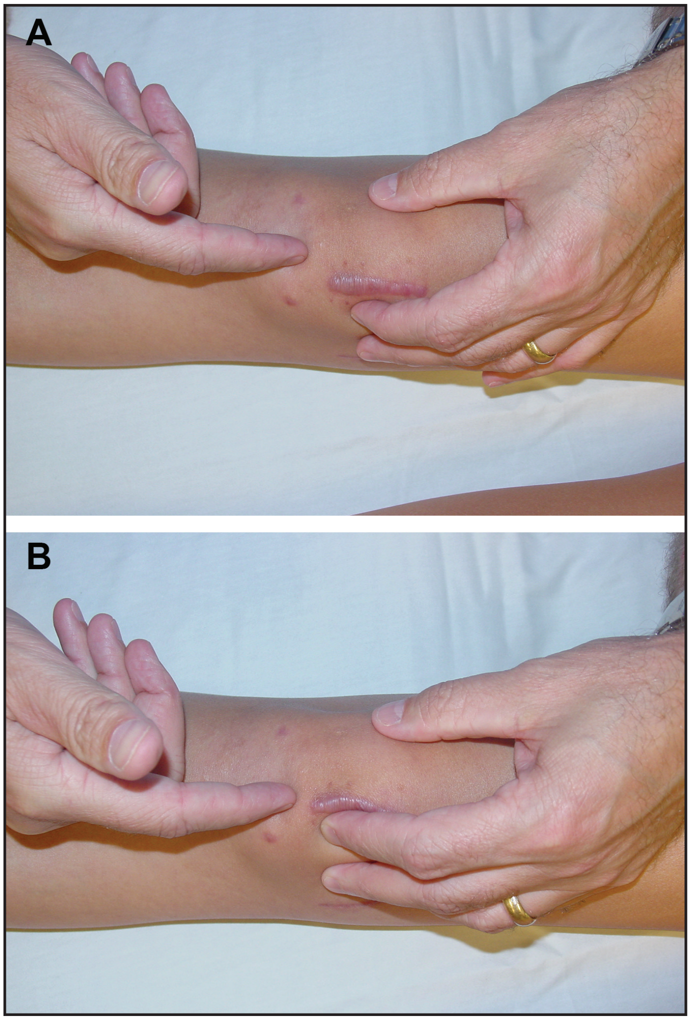

Figure 2. *Examination of passive patellar mobility. A) The examiner uses thumb to determine midline of patella to determine amount of translation, B) translation of the patella in the lateral direction assessing the amount of passive patellar mobility. Following MPFL reconstruction the desired amount of passive patellar mobility should be approximately 2 quadrants or half the width of the patella.*

INDICATIONS FOR SURGERY

Conservative treatment is universally attempted in an effort to strengthen the dynamic stabilizers of the anterior knee. When non-operative rehabilitation does not offer a satisfactory outcome regarding stability, surgical reconstruction of the MPFL may be offered. MPFL reconstruction has been shown to be an acceptable method to restore static stabilizing structures.[25,43-46] Historically traditional procedures to address patellar dysfunction such as medial retinacular reefing or the lateral release have been utilized to address chronic patellar instability but these often result in continued instability, anterior knee pain, and even medial patellar instability due to iatrogenic causes.[47-50] Indications for MPFL reconstruction include recurrent patellar instability that has failed standard nonoperative management. The role of MPFL reconstruction for acute patellar dislocation and isolated trochlear dysplasia has not been clearly determined as of the publication of this manuscript.

SURGICAL TECHNIQUE

Surgical reconstruction of the MPFL is performed in the following steps. A thorough examination under anesthesia is performed to assess ligament stability and evaluate the mobility of the patella with special attention to the lateral glide. This is checked both in extension (Figure 3) and in flexion (Figure 4).

Diagnostic arthroscopy is performed to evaluate the patellofemoral articular surfaces evaluating for any chondral damage and treating as indicated (Figure 5). Patellar articular surface injury may require debridement of loose cartilage or if severe may require a osteochondral repair type procedure in addition to the MPFL reconstruction.

Reconstruction of the MPFL should attempt to reproduce the native ligament, restore normal anatomy and function and is designed as a "check rein", but is not intended to be used as a harness to hold the patella centered in the trochlea. Multiple autograft choices exist including: a hamstring

Figure 3. *Pre-operative lateral patellar displacement with knee positioned in flexion. Taken from: Manske RC, Lehecka BJ, Prohaska D. Medial patellofemoral ligament reconstruction for patellar instability. SPTS Home Study Course, Indianapolis, IN. 2010.*

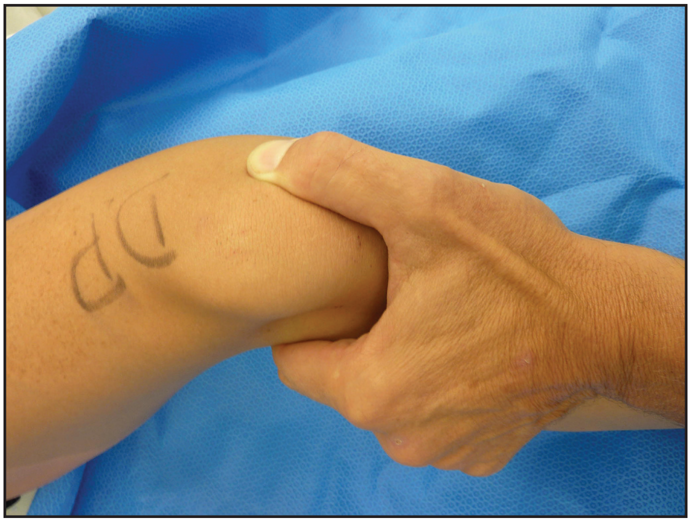

Figure 4. *Pre-operative lateral patellar displacement with knee positioned in full extension. Taken from: Manske RC, Lehecka BJ, Prohaska D. Medial patellofemoral ligament reconstruction for patellar instability. SPTS Home Study Course, Indianapolis, IN. 2010.*

Figure 6. *Location of double incisions used for MPFL reconstruction. Taken from: Manske RC, Lehecka BJ, Prohaska D. Medial patellofemoral ligament reconstruction for patellar instability. SPTS Home Study Course, Indianapolis, IN. 2010.*

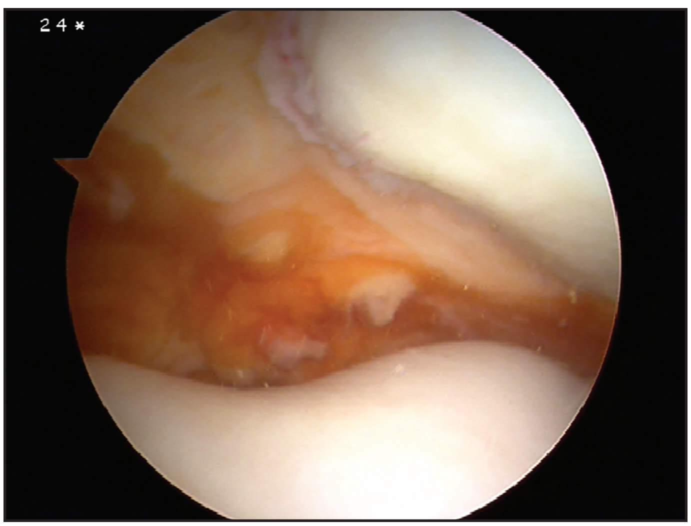

Figure 5. *Diagnostic arthroscopy demonstrating patellar instability.*

Figure 7. *solating hamstring tendons used for MPFL reconstruction. Taken from: Manske RC, Lehecka BJ, Prohaska D. Medial patellofemoral ligament reconstruction for patellar instability. SPTS Home Study Course, Indianapolis, IN. 2010.*

tendon,[43,45] the adductor magnus,[51,52] a portion of the quadriceps tendon,[53,54] or a medial strip of the quadriceps tendon. Each of these can be used leaving the patellar attachment intact. Allograft tissue has been used, with outcomes that are acceptable, including no undue risk for re-rupture, and no donor site morbidity.[55,56]

The graft is secured to the patella either by tunnels passing the graft through the patella and anchoring on the far side or with an interference screw, or by looping the graft through the patella with no actual fixation in the patella itself. A double incision is used for proper tunnel and graft placement (Figure 6). When using hamstring autografts, the hamstring tendons must first be isolated and procured (Figure 7). The graft is passed between the soft tissue layers from the patella to its position of attachment on the medial femoral condyle making sure that the graft stays outside the knee capsule.

Figure 8. *After graft fixation, tension is set so that there is no undue tension on the medial side. The graft should become a passive tether, not to create a medial pull. Taken from: Manske RC, Lehecka BJ, Prohaska D. Medial patellofemoral ligament reconstruction for patellar instability. SPTS Home Study Course, Indianapolis, IN. 2010.*

Figure 9. *Post-operative lateral patellar translation at 30 degrees of flexion showing excellent stability. Taken from: Manske RC, Lehecka BJ, Prohaska D. Medial patellofemoral ligament reconstruction for patellar instability. SPTS Home Study Course, Indianapolis, IN. 2010.*

It is important to use bony landmarks and often fluoroscopy is employed to ensure that the graft entrance to the femur is in the correct location. After fixation of the graft, tension is set so that there is no excessive strain on the medial side of the knee (Figure 8). The knee is taken through full range of motion to ensure that the graft does not change in length and tighten or loosen. For example, if the femoral site is too proximal, the graft will be tight in flexion, and so the tunnel needs to be repositioned. Failure to change the tunnel may lead to a knee that has excessive loss of flexion after reconstruction. Following graft fixation, lateral patellar translation is again assessed to ensure proper tension (Figure 9).

Fixation on the femur can be done with interference screw, anchors in bone, or distal button fixation.

Post operatively the knee is placed in a compressive soft dressing and cold therapy is utilized. Surgery is done on an outpatient basis.

REHABILITATION FOLLOWING MPFL RECONSTRUCTION

Return to activity following MPFL will follow a four phase progression of rehabilitation that gradually allows an increase in range of motion and quadriceps activation, in order to allow a full return to prior activity level. These four phases are typical of other postoperative procedures for the knee and include: Protective Phase (day one to week 6), Moderate Protection Phase (Weeks 7 to 12), Minimum Protection Phase (Weeks 13 to 16), and Return to Full Activity Phase (Weeks 17-20+). Because not all patients heal in the same speed or manner, within the descriptions of each of these postoperative phases, clinical milestones are listed which allow the clinician to better know when the patient can be progressed to another phase.

PHASE I: PROTECTIVE PHASE (DAY 1 TO WEEK 6)

Goals for this initial phase following reconstruction include protecting the repair, decreasing pain and inflammation, preventing the negative effects of immobilization, restoring knee range of motion and arthrokinematics, preventing hypomobility, promoting dynamic stability, preventing reflex inhibition and secondary muscle atrophy, developing neuromuscular control of the knee and maintaining core stability.

When MPFL reconstruction is performed independently, Phase I begins within 2-3 days of the surgery. This surgical procedure can also be performed concomitantly with a lateral release or distal realignment procedure and may require additional immobilization periods.

With isolated MPFL reconstruction, ambulation is weight bearing as tolerated and range of motion is progressed as tolerated immediately. Strict immobilization of the knee can result in loss of ground substance and dehydration and approximation of embedded fibers in the extracellular matrix of soft tissues.[57] Because the surgical reconstruction of the MPFL requires operating at or near the medial epicondyle of the knee, early motion is indicated. During flexion and extension motion at the knee there is substantial movement of soft tissues around the medial epicondyle and therefore stiffness and loss of motion is common.[58] Although some report a restriction of motion and weight bearing are required to protect against additional soft tissue injury following MPFL surgery,[59,60] the authors of this manuscript suggest that immobilization is not worth the risk of post-operative stiffness. To decrease this risk of stiffness, range of motion is initiated progressively and early. Immediate range of motion as tolerated is allowed because the MPFL experiences maximal loads near full knee extension and during early knee flexion range of motion.[28] As long as the graft is placed isometrically, increases in knee flexion range of motion should not place undue strain on the substitute tissue. Controlled mobilization reverses the effects of immobilization by stimulating collagen synthesis and optimizing alignment of healing tissues.[61,62] This is of particular concern in ligaments as studies in animals have clearly shown that following even a few weeks of immobilization results in marked decreases in structural properties.[63,64] These decreased properties occur due to subperiosteal bone resorption within the insertion sites as well as microstructural changes within the ligament substance. Remobilization was found to reverse the changes, however it took up to one year to return the properties to normal levels following only nine weeks of immobilization. A systematic review of eight papers of investigations following rehabilitation for MPFL reports that there is little differences in radiological or clinical outcomes between patients who were initially full weight bearing, began immediate active exercises, and were not immobilized in a knee brace, compared to those who were initially non-weight bearing, instructed not to exercise their knee, and were immobilized in a knee brace during the initial postoperative weeks.[65]

Because post-surgical pain and swelling are known to inhibit quadriceps muscle control, both cryotherapy and electrical stimulation are used to alleviate pain by decreasing nerve conduction velocity and releasing endogenous opiates.[66-70] In addition to these modalities the knee should be covered with a compression wrap of some form. The compressive dressing could be an ace wrap or "tube grip" type wrap to decrease existing swelling or prevent the onset of further swelling. The knee should also be kept in elevation early over the first 1-2 days following surgery.

Range of motion is initiated and progressed per surgeon's protocol. The native intact MPFL has a load to failure rate of 208N.[36,71,72] When the tibialis anterior is used as a graft substitute, its load to failure strength is 1553N,[73] while a single strand of semitendinosus load to failure strength is 1060N.[74] Due to the strength of substitute grafts, motion is provided to the knee and patellofemoral joint. After an assessment of passive patellar mobility, patellar mobilizations may be performed in all directions. Because knee motion stiffness and flexion contractures are one of the top complications following MPFL reconstruction,[75] the patella can be mobilized if passive mobility is limited. This is in direct opposition to Cheatham and colleagues[76] who report that only grade I and II superior and inferior glides are performed at the patellofemoral joint as they feel that medial and lateral glides may stress the surgical site. As long as fixation is appropriate concern regarding the stress of grade III and IV patellar mobilizations is not warranted. Patellar passive mobility of at least two quadrants in both the medial and lateral directions is desired. If there are less than two quadrants of passive mobility, joint mobilizations are instituted (Figure 10). As with most postoperative knee procedures the first post-operative priority is always gaining full extension to decrease the risk of developing a flexion contracture (Figure 11). Cyclops lesions, as seen with anterior cruciate ligament reconstructions, are not commonly reported following MPFL reconstruction, however capsular and or infrapatellar fat pad contracture, quadriceps inhibition, and poorly placed grafts can lead to motion complications.[58]

Figure 10. *Treatment of a hypomobile patellofemoral joint following MPFL reconstruction. Lack of passive mobility following reconstruction is one of the most common causes of surgical failure. If the athlete does not have a minimum of 2 quadrants passive patellar mobility, medial and lateral glide patellofemoral joint mobilizations may be required.*

Figure 11. *Obtain early full knee extension to prevent flexion contracture.*

The patient should ambulate weight bearing as tolerated progressing to full weight bearing for the first two weeks. Empirically, the authors have seen that typically the patient is full weight bearing within one week, however, it is not uncommon to reserve the second week for crutch use if needed or if pain and swelling persists for a longer amount of time.

Early exercises include quadriceps sets, heel slides, hamstring sets and gluteal sets until the patient is full weight bearing without symptoms. Because the hip and trunk are so important in maintaining proximal control for the knee and the patellofemoral joint, total leg strengthening (TLS) is initiated early. A phased approach is used to progressively strengthen the hip. The exercises used are based on electromyographic (EMG) studies demonstrating the hierarchy of maximal volitional contraction of the surrounding hip musculature.[77-80] Bolgla and Boling[81] performed a systematic review showing that both quadriceps and hip strengthening exercises are helpful to reduce pain in those with patellofemoral pain syndrome. They are also the mainstay during MPFL rehabilitation. Please see Table 1 for list of exercise in rank order based on percentage EMG activity.

If quadriceps inhibition occurs during this time frame, evidence has demonstrated neuromuscular electrical stimulation to be helpful in reducing strength loss after knee ligament surgery. Neuromuscular electrical stimulation should be performed with the athlete's volitional contraction in order to work optimally.[82-85] Empirically, the authors of this manuscript have found that performing the quadriceps contractions in weight bearing increases contractile output better than when performed supine in long sitting.

Because of the replacement graft immediate strength, a brace or immobilizer is not used. Better understanding of graft mechanics and graft loading has resulted in advancement of rehabilitation. Basic exercises can begin including straight leg raises in all four planes, ankle isotonic strengthening in all planes, heel slides, quadriceps, hamstring and gluteal sets and eventually isotonic hamstring curls. Once full weight bearing is achieved without issues, closed kinetic chain exercises can begin. These include heel raises, mini-squats, progressive step-ups and downs, and balance and proprioception.

Clinical milestones for a safe progression at the end of phase I include full non-painful knee range of motion, full weight bearing without antalgia or limp, no increase in pain or swelling, at least 2 quadrants of patellar mobility, and ability to stand on a single leg.

PHASE II: MODERATE PROTECTION PHASE (WEEKS 7-12)

Goals for the moderate protection phase include: 1) maintaining full range of motion, 2) maintain repair,

Table 1. *Rank Order of Mean EMG during Exercises for Gluteus Medius and Gluteus Maximus Muscles*[80]

Exercise	Gluteus Medius	Exercise	Gluteus Maximus
Side-lying hip abduction	81	Single-limb squat	59
Single-limb squat	64	Single-limb deadlift	59
Lateral band walk	61	Transverse lunge	49
Single-limb deadlift	58	Forward lunge	44
Sideways hop	57	Sideways lunge	41
Transverse hop	48	Side-lying hip abduction	39
Transverse lunge	48	Sideways hop	39
Forward hop	45	Clam in 60 hip flexion	30
Forward lunge	42	Transverse hop	35
Clam in 30 hip flexion	40	Forward hop	35
Sideways lunge	39	Clam in 30 hip flexion	34
Clam in 60 hip flexion	38	Lateral band walk	27

All values expressed as a % of MVIC.
Data reproduced from: Distefano LJ, Blackburn JT, Marshall SW, Padu DA. Gluteal muscle activation during common therapeutic exercises. *J Orthop Sports Phys Ther* 2009;39(7):532-540.

3) gradual initiation of functional activities. During this phase most restrictions have been lifted.

Range of motion should be fairly well established at this time. If not, emphasis on motion should take precedence so as to not end up with an arthrofibrotic knee. Higher grade mobilizations and gentle overpressure to end ranges should be instituted to normalize the arthrokinematics of knee flexion and extension.

Exercises for strengthening in phase II can include a progression of squats by adding weight or adding proprioceptive component by squatting on balance board (Figure 12). Other closed chain exercises can include lunges starting on level ground and progressing to lunging to labile surface. Leg press exercises should be performed both bilaterally (Figure 13) and unilaterally to ensure adequate stimulus to the post-surgical knee. Lateral band walking places significant load on the hip musculature and is a great exercise to progress proximal hip dynamic stability and control (Figure 14).

Other hip exercises that are effective at strengthening at this time are single leg bridge (Figure 15) and hip hiking (Figure 16 A and B). Balance and proprioceptive exercises provide training for a stable base for the rest of the body to move from. The importance of balance and proprioception in athletics cannot be denied. An attempt to regain lost proprioception,

Figure 12. *Performance of squat exercise on a balance board providing not only lower extremity strengthening but also a proprioceptive and balance training effect.*

regaining dynamic stability and neuromuscular control should be a priority. Neuromuscular training improves the nervous systems ability to generate optimal and fast muscle firing patterns, increases dynamic joint stability, and decreases joint reaction forces, which allows the muscles surrounding the joint to achieve a state of “readiness” to respond to joint forces and stimulus resulting in enhanced motor control.[85] Early forms of balance training can begin in partial weight bearing progressing to full weight bearing. These can occur as weight shifting

Figure 13. *Squatting on a leg press can increase the tolerable load in a controlled fashion.*

Figure 14. *Lateral band walking provides a method of incorporating additional strengthening effect to the hip abductors which are important proximal stabilizers to the leg and improves knee control.*

in all directions. Squatting on a balance board or foam pad can help challenge balance and proprioception. Ultimately single-leg balance exercises can be done by applying a light perturbation or by using distractive elements such as throwing and catching a ball while balancing. In this manner perturbation training is done to induce dynamic knee stability allowing patients to develop their own compensation strategies to maintain stability.[86]

Single-leg exercises can begin including single-leg squats. These should be assessed critically as

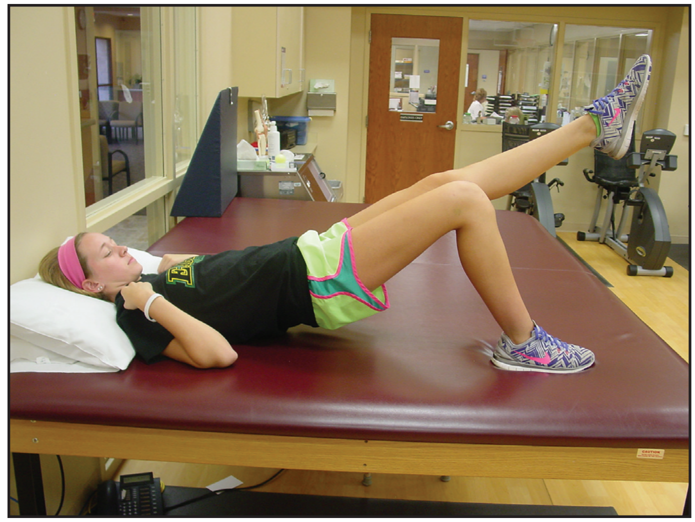

Figure 15. *Hip abductors are recruited highly with the lateral band walking drill.*

Figure 16. *A. Hip hike in the down position, B. Hip hike in the up position.*

compensations can occur. These compensations generally result in increased hip adduction, internal rotation and tibial abduction. These can be seen subjectively when performing a single-leg squat with poor control (Figure 17A). At times this can be improved through strengthening exercises however visual and verbal cues may help improve poor postural control (Figure 17B). The clinical milestones for the moderate protection phase are to maintain previous milestones and to have full strength of hip, quadriceps and hamstrings. These milestones are important to be able to tolerate higher level activities in the minimum protection phase.

Figure 17. *A. Single-leg squat can be performed to examine more functional movement patterns of the entire lower extremity. A) The patient demonstrates poor frontal, transverse and sagittal control. B) improved control is assisted by visualization in front of mirror and verbal cues.*

PHASE III: MINIMUM PROTECTION PHASE (WEEKS 13-16)

The minimum protection phase has the shortest time frame, which lasts from 13 to 16 weeks. The primary goals of this phase are to gradually return the athlete to functional activities.

To allow a gradual return to functional and athletic activities the involved knee has to have loads gradually applied up to that of the level needed to perform these higher functional activities such as running and jumping. This can be achieved by ensuring adequate strength through increased resistance and intensity during previous exercises such as squats, lunges, and leg press. Plyometric activities can begin with small bounding bilaterally such as double- leg jumping in place or double- leg jumping across multiple planes (Figure 18). Lateral and medial bounding can also be initiated which places specific stressors to the medial and lateral knee. Progressions of jumping/hopping should always start bilateral (jumping) and progressing to unilateral (hopping). Progressions to single-leg hopping are initiated in the next phase.

Clinical milestones to move into phase IV include all the prior milestones in addition to confidence in knee.

PHASE IV: RETURN TO ACTIVITY (WEEKS 17-21 +)

Goals for the return to activity phase include 1) progression of functional activities, 2) full return to all

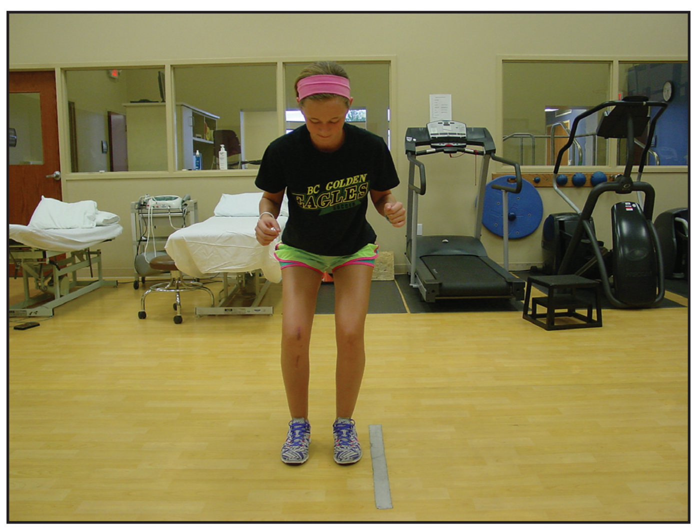

Figure 18. *Bilateral jumping without pain or symptoms.*

prior sports or recreational activities. In this goal the athlete is challenged at even higher levels of lower leg stressors that will determine if they are able to return to their prior sporting activities. This level may not be utilized for every patient. Not all patients that have MPFL reconstruction are higher-level athletes. If they do not desire or require this level of activity they would not be required to be rehabilitated to this level.

Once the athlete is comfortable with bilateral jumping they can attempt unilateral single-leg hopping on one foot. To start, it may be best to hop off of single affected side and landing on the unaffected side. Athletes following knee surgery are usually more able to hop from the surgical leg concentrically, but more concerned or afraid when asked to land eccentrically on the affected single-leg. Functional drills or activities such as sidestepping, ladder drills, or carioca can be done in a controlled manner to work on neuromuscular control. It is also at this last stage that the athlete can begin interval type programs such as return to running program.

DISCHARGE AND FULL RETURN TO COMPETITION

Discharge and full release and return to competitive sports is based on criteria that include: full range of motion, full strength and ability to achieve norms on standardized functional tests. The single leg step down test should be able to be performed with good form.[87] This test is performed with the patient standing near the edge of a 20cm step. The patient is asked to place hands on hips and flex the test knee enough to touch the floor gently with opposite extremity. Five repetitions are scored by giving a single point for 1) using arms to maintain balance, 2) trunk lean either medial or lateral, 3) pelvis rotation or elevation, 4) tibial tubercle moving medial to 2nd toe, 5) unsteady unilateral stance; while two points are given for the tibial tubercle moving medial to the foot. A good score is needed to return to sports. A good quality score is 0-1 point, medium quality is 2-3 points, and poor quality is 4+ points. The step down test has been shown to have good interrater reliability and has the ability to differentiate those with moderate quality of movement (those with less hip abduction strength and decreased quadriceps flexibility) compared to those with good movement qualities.[88]

Additionally, jumping and hopping tests are used. Criteria to be released for return to sports are for the athlete to be able to jump with both legs together horizontally 100% of height for males and 90% of height for females. Single-leg hop distances should be 90% of height for males and 80% of height for females. These are standardized norms for healthy non injured populations.[89]

Nomura and colleagues[90] followed 24 knees with after MPFL reconstruction for a mean follow-up of 11.9 years. Using the Crosby/Insall criteria and Kellgren/Lawrence grading systems and found that the association of knee osteoarthritis following MPFL reconstruction with or without a lateral release was small over the long-term. This is important as other surgical treatments such as proximal or distal realignments has been proven to be associated with osteoarthritis as early as 10 years following the procedure.[91-96] Furthermore, Lippacher and colleagues found that of those who participated in sports prior to MPFL reconstruction, 100% returned to sports.[97] Fifty-three percent returned to equal or higher levels, whereas 47% returned at lower levels. In those that returned to lower levels of athletics numerous reasons were cited including physical reasons such as decreased knee function and desire to avoid excessive sports after surgery, but also more psychological reasons too such as lack of time or interest and the fact that they were advised to be aware of the risks of high-pivot sports such as soccer.

PATIENT REPORTED OUTCOMES

Patient reported outcomes are instruments and rating scales used to measure outcomes from the patient's perspective. These outcomes may at times be very different from our clinical objective measures. These outcome tools examine many facets of knee health including swelling, giving way, pain and ability to function in activities of daily living. The authors of this manuscript recommend several following MPFL reconstruction. The Activities of Daily Living Scale[98] and the Sports Activity Scale[99] are both knee specific. The Sports Activity Scale have questions more related to higher levels of physical activity that are pertinent in active populations.

CONCLUSIONS

The science behind MPFL reconstruction and the ensuing rehabilitating continue to evolve as more evidence becomes available. The suggested protocol will help guide the patient to full recovery to sports and/or recreational activities without complications. An early emphasis on range of motion followed by a progression of strengthening exercises allows adequate incorporation of the soft tissue graft to the bony structures utilized during this reconstruction. Clinical milestones have been described to demonstrate when movement to the next phase is to be performed. MPFL reconstruction has been shown to have good results with low risk for major complications. As the surgery and the understanding of the MPFL continue to evolve so will the rehabilitation that follows. At present, clinicians must respect the soft healing tissue constraints but not at the expense of stiffness. Certainly higher levels of clinical research with longer follow up are needed to fully investigate the outcomes following this procedure.

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